CHAPTER 13
RANGELANDS AND GRASSLANDS

13.1 INTRODUCTION

Rangelands are lands generally characterized by low and/or erratic precipitation, poor drainage, rough topography, and often low soil fertility.[1] They occupy some 47% of the earth's surface (Heitschmidt and Stuth 1991). Fire, rainfall, soil type, and grazing animals are driving forces determining plant species composition, distribution, and productivity. Management of rangelands ranges from nomadic pastoralism, to subsistence farming, to commercial ranching. Many rangelands have been used the same way for thousands of years, while others have a relatively short history of use.

Carbon cycling and productivity in rangeland ecosystems are directly related to the amounts and seasonal distribution of precipitation and only secondarily controlled by other climate variables and atmospheric chemistry. Most carbon storage in grasslands, savannas, and deserts is below ground. Estimates done using the soil/plant simulation CENTURY model (Parton *et al.* 1987, 1992) suggest that 560 Pg C is stored in biomass and litter, while 1100-1400 Pg C is stored in roots and soils of the terrestrial biosphere, with the carbon in grasslands and savannas estimated at 417 Pg C (Sampson *et al.* 1993). However, rangeland productivity may vary as much as five-fold because of timing and amounts of precipitation (Walker 1993). Non-sustainable land use practices such as inappropriate plowing, overgrazing of domestic animals, and excessive fuelwood use are the root causes of the degradation of rangeland ecosystems (Ojima *et al.* 1993; Sampson *et al.* 1993). It is estimated that about 70% of the world's drylands are at least moderately degraded (Dregne *et al.* 1991).

Methane production by wild and domestic animals has been estimated to be around 80 Tg/yr (Cicerone and Oremland 1988) or about 15% of the world's total methane emissions. N_2O is produced as part of the N cycle and is subject to increases with alteration of the N cycle through land use changes (Ojima *et al.* 1993, Mosier *et al.* 1991). Temperate grasslands of the world are estimated to contribute 0.1 Tg N_2O annually or about 0.65% of the world's total sources of N_2O (Matson and Vitousek 1990).

13.2 OVERVIEW OF MITIGATION OPTIONS

Reduction of GHG emissions in the rangelands sector primarily involves the reduction of methane production by wild and domestic ruminant grazers, and increasing storage of carbon, which is dependent on improving rangeland health where needed. The dynamics of soil organic matter is one of the major indicators of change in greenhouse gas fluxes in grassland and rangeland ecosystems. Altering land use practices can influence the rate of changes in soil organic matter (SOM) levels and be used to mitigate efflux of CO_2 into the atmosphere. Good soil management is the key to maintaining or increasing carbon storage and protecting rangeland health. Improving rangeland health, and thus the amount and kind of vegetation, will also reduce methane emission from ruminant animals by improving the quality of their diet. Research suggests that small reductions in the number of grazing animals (stocking rate) or altering the timing of grazing could result in large soil sinks for atmospheric CO_2 (Metherell *et al.* 1993) and in methane emission reduction (Howden 1991, Galbally *et al.* 1992).

Table 13-1 (found at the end of this chapter) presents a list of options to improve rangeland health and also mitigate GHG emissions. Not all the practices listed are relevant to every country, social system, or rangeland type. The suggested practices will only be successful if local communities benefit from their

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[1] The term rangelands as used in this chapter includes grasslands and drylands.

implementation. None of the practices is likely to significantly improve rangeland health and carbon sequestration without adequate amounts and appropriate timing of rainfall. The most successful rangeland improvement projects for unhealthy rangelands were implemented in years of high rainfall (Heady 1988).

13.3 ANALYTICAL APPROACHES FOR RANGELANDS MITIGATION ASSESSMENT

There are two main approaches which can be used to analyze options for reducing GHG emissions or increasing carbon storage on rangelands. The first involves case studies based on existing rangeland management practices.

The CENTURY ecosystem model (Parton *et al.* 1987 and 1993) can be used to evaluate the effectiveness of various mitigation options for increasing or maintaining stocks of SOM and improving rangeland health in grassland and rangeland ecosystems. In developing simulations, data will be needed for weather, soil characteristics and spatial distribution of grassland and rangeland. Land use management data will be needed in order to simulate reasonable scenarios of current and alternate land use practices or mitigation options. In developing the mitigation options, identification of the key input and output variables (such as soil C levels, livestock production, plant productivity, N gaseous losses, etc.) is critical. The determination of specific mitigation practices that are appropriate for a particular situation needs to be identified and described in enough detail to be implemented in the model framework.

A key step in the initial phase of analysis is to describe the physical, biological, and the human-related characteristics of the study area that identify the critical factors affecting C storage and fluxes, and fluxes of other GHGs. The physical variables include information related to the climate and soil systems. The climate data to be defined for a site or region include the monthly average maximum and minimum air temperature and the monthly precipitation. Climate data collected over a range of years to capture the interannual and the decadal variations in weather patterns is desirable. The soil data needs to include information on soil texture, water holding capacity, soil pH, bulk density, and depth. Other physical data that are useful to have include topography and parent material type.

Biology information includes description of the vegetation, disturbance patterns, seasonal dynamics, and nutrient cycling. The vegetation information needs to include a general description of functional attributes of the components of the ecosystem, such as what percent biomass is contained in each category. What seasonal pattern of growth and mortality takes place in the different functional categories? What physiological and biogeochemical attributes does the dominant vegetation possess? For instance, data on the lignin content of plant material, plant C and N content, and the dominant photosynthetic pathway would be useful. In addition, if information on the current, and if available, on historical levels of soil C and N levels were available, analysis of changes in these components would be better documented.

Human activities affecting soil C and other GHG fluxes include land use management related to grazing, fire, animal residue, cropping patterns, harvest techniques, tillage practices, and fertilizer use. Modification in these land management practices provides the techniques to implement different mitigation options to reduce GHG emissions and increase C storage in grassland and rangeland ecosystems. Development of appropriate mitigation options will be determined by specific economic, political, and cultural characteristics of the situation that is being studied.

A second analytical approach involves a comprehensive assessment of the rangeland sector and its role in the country's formal and informal economy, including that of providing climate change mitigation. Analysis techniques which link ecosystem process studies across a range of environmental factors, such as climate, soils, land use, in a geographically explicit manner are currently being used. This analysis structure allows one to assess the regional impact of global environmental changes and the effectiveness of different mitigation options on soil carbon storage and other ecosystem feedbacks to the atmospheric system (e.g. H_2O, CH_4, and N_2O). This structure takes information from ecosystem process studies and from spatial data on soils, climate, land use, and policy-relevant information to make assessments of the impact of changing management practices for greenhouse gas mitigation.

A comprehensive assessment consists of the following elements:

- inventory of current rangeland area, vegetation, soil types, and demand for forage, fuelwood, or other uses;
- evaluation of the current condition (health) of ecosystem types;
- assessment of rangeland ecosystem change;
- assessment of future land area available for domestic grazing animals and wildlife, given the demand for land by other sectors;
- assessment of future demand for forage, fuelwood, agriculture, or other uses from rangeland ecosystems;
- projection of the land areas as well as the livestock and wildlife production under both baseline and mitigation scenarios;
- estimation of the potential for reducing GHG emissions and/or sequestering carbon for each option considered;
- estimation of the costs and non-GHG benefits of each option;
- based on the above analysis, identification of potentially attractive mitigation options;
- estimation of the potential carbon sequestration or GHG reduction for each mitigation option; and
- documentation of policies, institutional arrangements, and incentives necessary for the implementation of options.

In this approach, the analyst should examine the rangeland sector within the context of land-use demand by all sectors (see Chapter 10). Such a comprehensive approach will result in identifying a mix of practices which use the fewest sources (bio-physical, cultural, and economic) and interfere the least with established viable pastoral practices while aiding the mitigation of climate change. This approach will allow for a cost-effective implementation of a subset of the options depending on the individual country, pastoral system, local culture, and available land resource. This approach, which is similar to that for the forest sector, also reduces the possibility of double-counting of GHG flows, costs, and benefits.

13.4 DEVELOPING A BASELINE SCENARIO

The first steps are to use available maps and/or data to determine the location and amounts of rangeland vegetation, and to identify the existing patterns of livestock and wildlife use.

13.4.1 Assessing Rangeland Health

A baseline assessment of the ecosystem should lead to the categorization of rangelands as either healthy, at risk, or unhealthy, each providing a different potential for mitigation options. The evaluation of any option or practice will be undertaken against the background of this baseline assessment.

Rangeland health is defined as the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained (NRC 1994). Evaluation of rangeland health will provide the initial assessment of opportunities for increasing carbon sequestration on rangelands. No one factor is sufficient to evaluate rangeland health; three criteria are suggested (NRC 1994):

- **Degree of soil stability and watershed function**. Soil stability is directly affected by soil erosion through wind and water. Breakdown of soil structure, reduced infiltration and thus water holding capacity, reduced organic matter and nutrient cycling, compaction, reduced germination, change in species composition, and productivity are all potential ecosystem effects caused by increased soil erosion.

  The evaluation of soil erosion can be based on several environmental factors such as the presence of the A-horizon, rills and gullies, pedestaling, scour or sheet erosion, sedimentation fans, or dunes.

- **Evaluation of the integrity of nutrient cycles and energy flow**. The capacity of rangelands to provide goods and services to human populations depends on the ability of plants to capture sunlight through photosynthesis and on the accumulation and cycling of nutrients over time. Interruption of nutrient cycles through poor land-use practices can lead to degradation of rangeland vegetation, reduction in productivity, and thus changes in ecosystem potential for carbon sequestration.

  Indices that can be used to evaluate ecosystem integrity in nutrient cycling and energy flow include the distribution of plants (growth forms, life-forms, and species), the degree of fragmentation in litter distribution, rooting depth, and community distribution.

- **The presence of functioning recovery mechanisms**. Useful indicators of the ecosystem resilience might include increasing plant cover, increasing plant vigor, changes in kind and number of seedlings, changes in plant age-class distribution, and other community attributes which would lead to greater soil stability and improved nutrient storage and cycling.

13.4.2 Assessing Rangeland Ecosystem Change

Linear response to grazing pressure and fluctuation in rainfall has been assumed by early successional models of rangeland vegetation change. Under the succession model, soil productive potential remains constant and plant community composition and productivity changes in a predictable inverse linear fashion in response to grazing or drought, i.e., remove grazing animals and health improves, add animals and health declines.

Rangelands generally do not respond as the successional model predicts because annual variation in amounts and distribution of rainfall already results in a wide variation in annual productivity (Walker 1993). Coupled with fire, grazing, and human activities, and a combination of lag effects in community response (thresholds which are not easily re-crossed), and multiple trajectories, there appears to be a confusing array of potential community states.

A new conceptual model of rangeland ecosystem functioning was proposed by Westoby *et al.* (1989). The model requires a knowledge of the changes that can take place in a particular rangeland and what causes them. Its value lies in making the understanding of community dynamics explicit. The most significant advantage of using this model to understand rangeland ecosystem dynamics is the recognition that the future may contain an array of possible states, dictated by an oncoming stream of events, and presenting a mixture of opportunities and hazards. The objective of rangeland management then is to seize the opportunities and as much as possible avoid the hazards (Walker 1993).

With this framework in mind, countries can evaluate existing rangeland condition (health), catalogue existing and potential states, catalogue management and natural events that cause transitions from one state to another, and evaluate which states provide the greatest opportunity for increasing carbon sequestration and/or reducing GHG emissions.

Particular combinations of rainfall, topography, soil type, and biological composition give rangelands individual characteristics, which, when coupled with different kinds of human use, make a state-transition model a useful conceptual tool for evaluating potential ecosystem response and thus the opportunity for carbon sequestration.

13.5 ANALYSIS OF MITIGATION OPTIONS

13.5.1 Potential Mitigation Practices

Table 13-1 identifies the kinds of practices which affect livestock and wildlife populations and the rangelands upon which they graze. If implemented, these practices will have different effects on reducing methane or increasing carbon storage. Different rangelands and social systems will require application of different mixes of practices. Although ecological, social, and economic costs and benefits are qualitatively addressed, issues of biodiversity and genetic conservation of plants and animals for future uses are only hinted at. The evaluation of different mitigation practices gives rise to different issues as shown in the following classes of mitigation options:

- Rehabilitation of degraded rangelands offers a very attractive opportunity to sequester carbon. The most likely practices under this option include afforestation, reforestation, grass and shrub establishment, control of grazing lands, halophyte establishment on salinized lands, etc. (Glenn *et al.* 1992). In an assessment of costs of rehabilitating the degraded rangelands of the world by applying a combination of the above practices, UNEP (1991) estimated that it will cost about US$5-8.8 billion per year over a period of 20 years. The CENTURY model was used to estimate the carbon flux difference between the baseline and the sustainable management scenario; the estimated benefit was about 0.7 billion tons of carbon per year (Ojima *et al.* 1993). This amount is equivalent to a cost of US$10 per ton of carbon sequestered, which is comparable or superior to the estimates in the forestry sector.

  The desirability of this mitigation option is further enhanced by the fact that most of the carbon sequestration in rangelands is through soil storage, which has a half-life of hundreds of years a period much longer than that for carbon sequestered in above-ground biomass. The process of undertaking cost-benefit analysis for rangeland rehabilitation is similar to that described in the forestry chapter.

- The viability of reducing livestock numbers will depend on the value of livestock to local and national economies and the value of animals as a social resource. For example, in sheep grazing systems in Australia, Howden (1991) found linear relationships between methane and nitrous oxide emissions and stocking rate. Using DYNAMOF, a simulation model, they showed that reducing emissions by 20% without any technological changes required an 18% reduction in stock numbers with a 15%-17% reduction in net cash income. However, using GRASSMAN, an agricultural decision-support model, Howden showed that changing the time of lambing, reducing stock in overgrazed areas, and managing fire frequency led to a significant reduction in GHG emissions without substantial effect on net income.

- Changing the mix of animals depends on the kind of rangeland and proposed mix of animals. If a country is considering only cattle and small stock (sheep or goats, etc), the mix may not be ecologically efficient; rather it may reflect an economic risk aversion where in bad times cattle die but goats survive. In this kind of grazing mix, the ecosystem may deteriorate. A mix of cattle and wildlife ruminants may be both ecologically and economically efficient.

- Changing animal distribution through salt placement, development of water sources, or fencing can increase carbon sequestration through some increase in plant cover and improved health of the root system through lighter intensity of grazing. However, none of the changes in animal distribution is expected to affect methane production.

- The practices most likely to reduce methane emissions from domestic and wild ruminants involve improving the quality of the diet. Providing protein supplements is one alternative. However, increasing native grasses and planting other adapted, productive species (such as halophytes where appropriate) will provide additional benefits to local communities and economies.

- Other practices like application of herbicides, use of mechanical methods to rehabilitate unhealthy rangeland, and watershed scale developments involve greater ecological, social, and economic costs. Specific values are not given in Table 13-1 because they vary depending on specific goals, rangeland health, and country. Economic costs can be derived from Heady (1988), Valentine (1990), and Child *et al.* (1987).

13.5.2 Physical Criteria for Evaluating Mitigation Options

The nature of each mitigation practice will determine the type of physical criteria needed to evaluate the option. For the rehabilitation practices, the area in which the option can be implemented every year for the duration of the practice should be identified. The sum of the annual areas will form the maximum area available for the mitigation option. The schedule of implementation will be dictated by the size of the area and practical considerations regarding range and livestock management. Quite possibly, some of the above mentioned practices can be carried out on the same land area with cumulative effect on emission reduction and/or carbon sequestration. In general, the following physical criteria should be estimated:

- **Land Availability**. The land on which each mitigation option would be implemented should be identified. The schedule of possible implementation should be used to estimate the total area available for the practice.

- **Emissions Reduction and/or Carbon Sequestration**. Carbon flows associated with each option at all stages of the project, including emissions from biomass burning, salvage, use of wood products, and emissions from soil disturbance should be estimated. Other trace GHGs such as CH_4, N_2O, NO_x, and NMHC should be estimated if the option in question will avoid the emission of significant quantities. In most of the options listed above, a substantial decrease in methane emissions is expected, and this should be estimated using known figures for methane emission per body weight of an animal.

  Estimates of uptake by vegetation and soils within the area should be done on the basis of net primary productivity of the woody biomass, including the net storage in soil and detrital material.

Applying these estimates to the total area available for each specific option, one can obtain the total carbon sequestration or emission reduction for the option.

13.5.3 CENTURY Model Application for Rangeland Mitigation Assessment

CENTURY is a general ecosystem model which simulates plant-soil dynamics of grasslands, forests, crops and savannas. The model runs using a monthly time step. The major input variables for the model include: (1) monthly average maximum and minimum air temperature; (2) monthly precipitation; (3) lignin content of plant material; (4) plant C and N content; (5) soil pH and soil texture; (6) atmospheric and soil N inputs; and (7) initial soil C and N levels.

The model has three major submodels. These include:

- a biophysical submodel which calculates hydrological and temperature drivers;
- a plant production submodel which calculates above- and below-ground plant processes; and
- a soil organic matter submodel that calculates changes in soil C and N and plant detritus.

The biophysical submodel is used to determine rate constants of decomposition, potential and actual evaporation and transpiration rates, and plant growth and death rates derived from climate and soil properties of a site or region. Inputs of monthly average maximum and minimum air temperature, monthly precipitation, and soil texture are used to determine soil temperature, soil water balance and other biophysical control factors for ecosystem dynamics.

The plant production and the soil organic matter (SOM) submodels are used to evaluate changes in C levels for different plant and soil components of the ecosystem. Units of these plant and soil pools of C are expressed as grams C per unit area (i.e., g C / m^2). Additional functions are used to simulate various land use management or disturbance regimes, such as forest planting, cropland conversion, fire, or grazing intensity and frequency. Appendix 13-1 provides further description of the CENTURY model and its use in simulating fire and grazing effects in grassland and rangeland ecosystems.

13.5.4 Evaluation of Economic Criteria

The options in the rangelands may require a gradual transition from the current rangeland health to a new sustainable equilibrium. As the state of the range improves, the carrying capacity will also change, and there will be a change in the flow of GHG associated with each state. The economic evaluation requires one to track the value of costs and non-GHG benefits over the transition period and compute the discounted value. Once the health of the range is restored, and the optimal mix of animals and diet quality is determined, the net change in GHG and value of resources needed can be assumed to continue in perpetuity. The net present value (NPV) of the perpetual stream of net benefits can then be compared to the corresponding net emission reduction.

- **Physical Inputs and Outputs**. The first step is to identify and quantify all necessary physical inputs required for implementation of each option during the initial operations, management, harvesting (if applicable), etc. These should include estimates of land, labor, equipment and material needed to support the project or option throughout its lifetime. For all options, one also has to identify constraining factors such as expertise, technology, and capital investment because these factors may affect both the cost as well as the implementation possibility of the option.

  Together with the physical inputs, one has to estimate the physical output in terms of desirable products like number of animals, wool, milk, and other products as applicable.

- **Unit Costs and Benefits**. For each of the physical inputs, one has to estimate the unit cost at the time of use. For each of the physical outputs of desirable products, an estimate of its price is necessary.

  The costs of a mitigation option include (1) the present value of the stream of expenses sufficient to cover the project's planning, development, occasional and recurrent expenses, and (2) the present value of the project's opportunity cost. Other cost components such as land rental (opportunity costs), maintenance, and monitoring and evaluation may need to be included if applicable. The opportunity cost is important since it captures the benefits derived from land use in the absence of a mitigation option, given the current land-use patterns. Opportunity cost may be evaluated using various methods, depending on the land in question and the likelihood of producing various goods and/or services if it is not used for the given option. These approaches include land rent, land market price, and net benefits obtainable from an alternative land use. In all these cases, land values and benefits from alternative use should be adjusted to account for existing significant price distortions due to subsidies, zoning regulations, etc.

  In addition to GHG impacts, the implementation of a mitigation option will result in other monetary and non-monetary benefits. Direct benefits may include goods such as livestock and services such as recreation. Indirect benefits may include such items as employment for local inhabitants and watershed protection.

13.5.4.1 Cost-effectiveness criteria

- **Initial Cost per ha and per tC**. This indicator provides useful information on the amount of resources required at the beginning to establish the project.

- **Endowment Requirements per ha and per tC**. The requirements are the sum of initial cost and the discounted value of all future investment and recurring costs during the lifetime of the project. For projects which do not have substantial monetary benefits, this indicator is quite useful because it provides the endowment necessary to maintain the project in perpetuity.

- **Net Present Value (NPV) per ha and per tC**. This indicator provides the net direct benefit to be obtained from the project. For most range improvement options as well as animal-based practices (e.g., animal mix change), the NPV indicator is expected to be positive for the option to be attractive. A benefit:cost ratio of all discounted values also provides a good measure of profitability.

- **Benefit of Reducing Atmospheric Carbon (BRAC)**. This indicator expresses the NPV of a project per unit of atmospheric carbon reduced by a mitigation option. In the case of other GHGs, this indicator can be computed on the basis of CO_2-equivalent GWP (see Chapter 2). The formulation of the indicator varies with the rate at which economic damage might increase, and it allows time-dependent evaluation of atmospheric carbon as may be deemed necessary.

- **Imputed and Non-monetary Costs and Benefits**. After compiling the criteria given above, all the identifiable costs and benefits which one is currently unable to evaluate should be listed for each mitigation option. Imputed values should be listed separately from the direct costs and benefits. The intangible benefits and costs should also be listed for each mitigation option. To the extent possible, one should identify the likely bearers of costs and benefits, including the non-monetary items. Although there may not be a coherent method for comparing the non-monetary and intangible costs and benefits associated with each option, their enumeration helps the policy-makers in the choice and implementation of the various mitigation options.

13.6 CONSTRUCTING A MITIGATION SCENARIO(S)

Having compiled physical, economic, and other information for each mitigation option, one can construct mitigation scenarios that show the aggregate impact of selected options. The impact of each mitigation option is measured against the baseline scenario developed for rangeland ecosystems.

One useful way to summarize the results is a supply curve for emissions reduction or carbon sequestration. For example, the initial cost per ton of carbon stored can be used to plot a curve which shows the amount of carbon that could be stored at increasingly higher initial cost. The other indicators like endowment requirement or NPV or BRAC could also be used to plot similar curves.

To construct a cost/supply curve, the unit values (cost and carbon storage per hectare) are combined with the area available for each option to obtain estimates of total emissions and costs of each option. Methane abatement can be treated in a similar fashion, either in terms of tons of methane or CO_2-equivalent GWP.

13.7 POLICY CONSIDERATIONS

It is important to recognize that rangelands are variable and episodic, and that vegetation response is not linearly related to change in livestock number. Thus, risk management strategies would include long-term, low stocking, or changing animal numbers annually and tracking annual variation in precipitation. Either approach requires flexible management response to different events, opportunities, and hazards.

Another policy consideration is that although rangelands have historically been used for livestock production for meat, wool, hides, milk, blood, and/or pharmaceuticals, an equally important objective may be to maintain the maximum number of animals as a social resource. Rangelands are also increasingly affected by human activities for mineral production, construction materials, fuel, and chemicals. Additionally, rangelands provide habitat for wildlife, threatened and endangered species, anthropological sites, and recreational activities. As the human population grows, rangelands also incur increased demand for marginal agriculture production. All these activities and uses potentially affect rangeland health and thus the potential of the ecosystem to sequester carbon.

Table 13-1. Practices to Improve Rangeland Health and Mitigate GHG Emissions.*

Practice	Healthy rangeland	Unhealthy rangeland	Carbon	Methane	Bio/physical benefit/cost	Social/cultural benefit/cost	Economic benefit/cost	General comments
Reduce animal numbers (in animal unit months (AUMs)	No	Yes	Increases carbon sink because of increasing vegetation cover and better root growth	Reduces animal methane production through reduction in total number	Increases plant cover, increases soil organic matter, and improves productivity	Depends on country and value of animals as a social resource	Depends on value of livestock products to national and/or local economy	Positive eco- system effect if sufficient rainfall. May require alternative sources of local food support, thus changes in food production policies
Change mix of animals	Yes	Yes	Possible increase in carbon sink with change in plant species	No known effect	Potential changes in plant species composition	Depends on country and cultural value of specific animal type	Depends on value of livestock products	Positive effect in general, improves efficiency of utilization
Alter animal distribution by placement of salt	Yes	Yes	Increases carbon sink because of increasing vegetation cover overall	No effect	Useless in rangeland areas already high in salt	Appropriate in countries where animals graze extensively rather than being herded	Cost of salt and distribution of salt	Positive. Not applicable for herding systems
Alter animal distribution by placement of water sources	Yes	Yes	Increases carbon sink because of increasing vegetation cover overall	No effect	Developed water resources may not be sustainable. Potential cost to long-term productivity	May affect territorial and property boundaries	Motorized water sources are often too costly to purchase or maintain	Negative if used to increase numbers of animals. Positive if used to alter animal distribution

* The possible effect of implementing a practice is given for carbon and methane, and qualitative cost/benefits estimates are provided. Unhealthy rangelands are those lands where soil loss, plant species and cover loss, species invasions, and interrupted and poorly functioning nutrient cycling are the norm. Healthy rangelands, on the other hand, have nutrient cycling and energy flows intact, soils are not eroding, and plant species composition and productivity is indicative of a functioning ecosystem.

Table 13-1. Practices to Improve Rangeland Health and Mitigate GHG Emissions - continued *

Practice	Healthy rangeland	Unhealthy rangeland	Carbon	Methane	Bio/physical benefit/cost	Social/cultural benefit/cost	Economic benefit/cost	General comments
Alter animal distribution by placement of fences	No	Yes	Increases carbon sink because of increasing vegetation cover overall	No effect	Benefit is to control domestic animal number and distribution	Depends on country and livestock/ wildlife system. Costs potentially outweigh benefits	Varies depending on country and source and kind of materials	Potentially interferes with wildlife migration
Provide livestock protein supplement	Yes	Yes	No effect	Decrease methane production	Perhaps will reduce extensive grazing to some degree	Possible where animals are herded	Cost of protein blocks or similar supplement	Potentially difficult to distribute to local areas
Increase native grasses and or plant adapted species	No	Yes	Increases carbon sink because of increasing vegetation cover overall	Possible benefit of methane reduction by increasing quality of diet	Benefit in retention of native species for gene conservation	Local people rely on native species for medicine and other health- related goods	Depends on the value of the livestock and wildlife products, and value of herbal medicine	Potential unknown benefits from native species. Adapted species survive in long term
Selective application of herbicides	No	Possibly	Potentially increase carbon sink	Potentially increase if expand animal numbers	Cost if non-target species, pollution of water, damage to food chain	Cost if non-target species, pollution of water, damage to food chain	Varies depending on country and source of herbicide	Cost if non-target species, pollution of water, damage to food chain
Mechanical treatment or restoration	No	Possibly	Potentially increase carbon sink	Potentially increase if expands animal numbers	Potential for large-scale alteration of soil and vegetation	May not fit pastoral system	Varies with country depending on availability of equipment	Benefit depends on success of treatment relative to disruption of ecosystem

Table 13-1. Practices to Improve Rangeland Health and Mitigate GHG Emissions - continued *

Practice	Healthy rangeland	Unhealthy rangeland	Carbon	Methane	Bio/physical benefit/cost	Social/cultural benefit/cost	Economic benefit/cost	General comments
Plant halophytes (salt tolerant-species)	If appropriate	If appropriate	Increase carbon sink and increase productivity	No known effect	Benefit with increased plant cover and productivity	Benefit with increasing forage production for livestock and wildlife	Cost of planting and maintaining with irrigation	Brings into production otherwise non-productive land
Apply prescribed burning	Yes	Yes	Increase carbon sink and increase productivity in the long term on appropriate rangeland types	Possible benefit of methane reduction by increasing quality of diet	In systems adapted to fire, can increase productivity, maintain nutrient cycling	Use of fire can be part of social system. Utilizes local knowledge	Threat of wildfire and destruction of resources	Short-term increase in CO_2 to atmosphere, long-term benefits in adapted systems
Implement agroforestry systems	Yes	Yes	Increase carbon sink and increase productivity in the long term on appropriate rangeland types	Possible benefit of methane reduction by increasing quality of diet	Possible benefit with increased plant cover, diversity, and productivity	Benefit with increasing forage production for livestock and wildlife	Cost of planting and maintaining	Increases carbon storage in trees. Benefit in diversity and productivity if adapted species
Develop large scale watershed projects	Possibly	Possibly	Increase carbon sink and increase productivity	Benefit, methane reduced by increasing quality of diet	Potential for large land disturbance, with benefit to human and animal populations because of regulated and regular water supply	Potential for improved food production, both plant and animal	Cost of dams etc, benefit hydro-electric power	Potential for increased human and animal populations because of increase in water

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APPENDIX 13-1
THE CENTURY ECOSYSTEM MODEL

The plant production submodel simulates grass growth and includes the impact of grazing and fire on plant production. Potential plant production is calculated as a function of soil temperature, available water and a self-shading factor. The effect of moisture on plant production is a function of the ratio of current monthly precipitation plus the previous month's stored soil water to the potential evapotranspiration rate. The soil water holding capacity also influences plant production by modifying the amount of stored soil water so that lower water holding soils (e.g., sandy soils) have a higher growth rate under dry conditions. The potential plant production rate is reduced if there is insufficient N. A maximum and minimum C to N (C:N) ratio is specified for new production of live roots and shoots. The model calculates root/shoot ratios as a function of the annual rainfall.

The SOM submodel simulates the dynamics of C and N in the organic and inorganic parts of the soil system. The flow diagram for soil C shows that soil C is divided up into three major components which include active, slow, and passive soil C. Active SOM includes live soil microbes plus microbial products (the total active pool is approximately 2 to 3 times the live soil microbial biomass); the slow pool includes resistant plant material (for instance, lignin-like components) and soil-stabilized plant and microbial material, while the passive material is very resistant to decomposition and includes physically and chemically stabilized SOM. The flows of C are controlled by the inherent maximum decomposition rate of the different pools and the water and temperature-controlled decomposition factor. Average monthly soil temperature at the soil surface controls the temperature function, and the ratio of stored water (0-30 cm depth) plus current monthly precipitation to potential evapotranspiration is the input for the moisture function. Microbial respiration occurs for each of the decomposition flows. The partitioning of decomposition between stabilized SOM and CO_2 flux is a function of soil texture for the stabilization of active C into slow C (increasing CO_2 flux for sandy soils and less soil C storage).

Plant residues (shoots and roots) are partitioned into structural (resistant to decomposition) and metabolic (readily decomposable) plant material as a function of the initial residue lignin (L)-to-nitrogen (N) ratio. The lignin fraction is assumed to be part of the structural material and (i.e., L:N ratio) controls the decomposition rate of structural material.

The organic-N flows follow the C flows and are equal to the product of the carbon flow and the N:C ratio of the state variable that receives the C. The C:N ratios of the soil state variables receiving the flow of C are a function of the mineral N pool (NO_3^- plus NH_4^+) and vary within the ranges 3-15, 12-20, and 7-10, respectively, for active, slow, and passive SOM. The C:N ratio of newly formed surface microbial biomass is a linear function of the N content of the material being decomposed and increases from 10 to 20 as the N content decreases from 2.0% to 0.01%. The C:N ratio of slow SOM material formed from surface microbes is equal to the C:N ratio of the microbes plus 5.0. N associated with carbon lost in respiration is assumed to be mineralized. Given the C:N ratio of the state variables and the microbial respiration loss, decomposition of metabolic residue, active, slow, and passive pools generally results in net mineralization of N, while decomposition of structural material immobilizes N. The model also uses simple equations to represent N inputs due to atmospheric deposition and N fixation and calculates N losses due to N_2, NO, N_2O, and NH_3 gas fluxes and NO_3 leaching.

Simulated fire and grazing effects in grassland and rangeland ecosystems. The major impact of fire is to increase the root to shoot ratio, increase the C:N ratio of live shoots and roots, remove vegetation and return nutrients during the years when fire occurs. The effect of different intensities of fire in herbaceous vegetation can be parameterized by specifying the fractions of live shoots, standing dead and surface litter removed by a fire along with the return of N, P, and S in inorganic forms.

Grazing removes vegetation, returns nutrients to the soil, alters the root to shoot ratio, and increases the N content of live shoots and roots. The model has three options for dealing with the impact of grazing on the system. First, a zero-direct effect option where there are no direct impacts of grazing on plant production except for the removal of vegetation and return of nutrients by the animals. Secondly, a linear negative impact option where grazing on plant productivity results in a linear decrease in potential plant production with increasing grazing intensity while holding root:shoot ratio constant. The third option employs an optimal grazing effect where plant production is increased for low to moderate grazing (grazing removal less than 35%) and decreases sharply for heavy grazing levels (>40% removed per month). The root:shoot ratio is constant for low to moderate grazing levels and decreases rapidly for heavy grazing levels. In all three options, the nutrient content of new shoot will increase in relation to the residual biomass.

The grazing options can be parameterized to remove defined fractions of above-ground live and standing dead plant material each month. The fractional returns of C, N, P, and S are specified, having allowed for losses in animal carcasses and milk, transfer of dung and urine off the area being simulated, volatile losses of N from dung and urine patches, and leaching of N and S under urine patches. The proportion of N, P, and S returned in organic forms is also specified as is the lignin content of the feces.